Decision Support for Marketing via Fuzzy Reasoning

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Using Toulmin¥s model of syllogistic reasoning with fuzzy quantifiers, expert knowledge in market research and pricing has been modelled in the form of fuzzy constraint nets in order to support managerial decision making.

These constraint nets are used to integrate data from different market research panels and to identify significant changes between reference periods. By comparing the corresponding structures in the data and in the modelled expertise it is possible (i) to identify those changes in the data which are of specific interest for the manager, and (ii) to check the validity of the managers intuitions empirically. The knowledge-guided analysis of data results in a listing of options for marketing policies and allows the user to simulate the consequences of different price cuts.

This approach has been developed in cooperation with leading consumer goods corporations in Germany. The analysis of marketing data reveals that in comparison with the traditional methods of linear and curvilinear regression the constraint-net model improves the prediction of sales and returns from about r = .25 to r = .75.

In the light of these results general questions of decision support in marketing are discussed.

KEYWORDS: fuzzy syllogistic reasoning, modelling managerial expertise, decision support in marketing

1. Introduction: Two Modes of Information Processing - Reasoning and Decision Making

Real-world problems that confront everyday man when choosing a career or decision specialists like supreme judges when declaring a law as constitutionally valid are characterized by unique combinations of cognitive processes which are usually treated separately in domains of psychology, namely, reasoning and decision making. Other similar situations are: The risk analysis for complex technological projects, predictions in economics, the evaluation of circumstantial evidence in the judicial process etc.. In all these cases there are some areas of knowledge where unequivocal facts are linked by unequivocal rules, there are other areas where a-priori no singular facts are known but only ensembles of facts and where relations between these ensembles can only be characterized statistically, and, finally, there are areas where facts and relations are principally well defined but too complex for an analytical treatment. However, for lay people a decision will only be regarded as satisfactory if all relevant aspects of knowledge are taken care of, in contrast, scientists approach this problem by decomposing it and usually concentrating upon the aspect which is defined best and allows an algorithmic treatment.

For this reason, in economics and psychology as well as in technology one can observe 'warring camps' of scientists. Proponents of one side suggest a predominantly statistical approach in terms of states, actions, risks, and outcomes, this is the classical approach of decision making or statistical risk analysis. Proponents of the opposite side tend to reduce the complexity by confining the analysis to those parts of the knowledge base where facts and relations can be unequivocally determined and analyzed in simulations which in turn result in scenarios.

In the Western tradition of philosophy, logic, and psychology until the end of the last century it has been regarded as a truism that logic is the language of thought. The scope of this Aristotelian position has been exemplified by Leibniz¥ claim about an artificial language integrating a descriptive language of concepts and the formal language of logic: ÑIf controversies were to arise, there would be no more need of disputation between two accountants. For it would suffice to take their pencils in their hands, to sit down to their slates, and to say to each other (with a friend to witness, if they liked): Let us calculate.ì Even in our century we can find vestiges of this tradition e.g. in Carnap¥s quest for the ¥Einheitswissenschaft¥ based upon the context free language of basic sentences and the rules of logic, aided by the probability calculus as developed by Boole.

The rise of psychological investigations of thought processes has debunked the notion of logic as an - albeit normative - theory of human reasoning. The question, however, if and how formal approaches of reasoning and human reasoning can be brought together, remains open. The approach proposed here is intended to close the gap somewhat by proposing what could be termed an approach to a formal theory of informal reasoning (Zimmer 1984a).

One can regard the formal (or mechanistic) approaches of logic and decision theory as two distinct but equally accepted modes of scientific reasoning, however, especially in the domain of applied science and even more in everyday reasoning the distinction between these approaches is at least blurred, in many situations it is even the case that an argument appears only as acceptable if it contains statistical

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(decision oriented) as well as deductive (logical) elements.

The richness of argumentative structure so salient in everyday reasoning (including the reasoning of experts in the applied realm) is coupled with the well known limitations of this kind of reasoning: It is biased towards confirmation, representativeness, and availability and it is limited in the amount of information (factual as well as formal) that can be processed at the same time. Effective support systems must therefore have a rich structure able to mirror the expert knowledge but at the same time have the unequivocality and processing power of mechanical approaches. The goal of this paper will be to sketch a framework for such a system and to give an example where it has been applied in marketing.

2. Schemes for Reasoning and Argumentation

In order to make more specific what such an approach is intended to achieve, it seems appropriate to compare 'classical' formal approaches, that is, predicate calculus and probability theory, with what is known about everyday reasoning. In Table 1 the positions of predicate calculus, probability theory, and everyday reasoning regarding central problems of reasoning are compared.

The inspection of Table 1 highlights the fact that, in general, predicate calculus and probability theory take very similar approaches towards problems and modes of reason-

ing despite their different structure. Exceptions, however, are the evaluation of partial or circumstantial evidence and in the weighing of evidence by probabilities or by divers colloquial qualifiers; here probability theory and everyday reasoning take similar positions. What distinguishes these points from the rest of Table 1? They apply to situations where only approximate solutions are possible, where the reasoning does not lead either to the alternative "true/false" or is invalid, but where only degrees of plausibility or veridicality can be reached.

As Toulmin (1964) observes, standard logic has been developed with an eye on mathematics where such ambiguous situations are to be avoided at nearly any cost (but see, for instance, Kline 1980). In order to liberate logic from this Procrustean bed, Toulmin suggests the reconstruction of logic according to the model of legal argumentation. He suggests a scheme of syllogistic reasoning with the following components:

(i)   claims propositions that are supposed to be true or to be at least plausible to a certain degree

(ii)   grounds or reasons for believing the claims to be valid (the usual form is that of explicitly or implicitly quantified statements)

(iii)   warrants, that is, statements about the relations between grounds and claims (e.g. causality, necessity, sufficiency, contingency)

(iv)   backing, that is, commonly shared knowledge (Smith 1982) which provides the rules for a combination of grounds and warrants in order to justify the claims (e.g. rules of syllogistic reasoning or statistical inference)

Table 1: Comparison of models of reasoning

	Predicate Calculus	Probability Theory	Everyday Reasoning
law of the excluded middle	**valid** without specification	**valid** in the definition of the event space	**usually not valid** except for easily enumerable ensembles
Modes of reasoning: ● deduction	**valid** without exception	**valid** without exception	**valid** but the result looses plausibility with the length of the deductive chain
● induction	**not valid**	**not valid** in classical approaches (v.Mises, Popper) **valid with restrictions** in non-standard approaches	**valid** if many convincing analogies can be brought forward
evaluation of partial or circumstantial evidence	**not possible** except for non-standard approaches (non-monotonic reasoning, default reasoning)	**possible** by means of Bayesian or information theoretic schemes	**possible but biased** because of heuristics and/or characteristics of memory (primacy and recency)
use of qualifiers	only standard quantifiers (all, some, not all, none)	not defined except for weighing by probability	without restrictions

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(v) modal qualifications, general quantifiers and uncertainty expressions, for instance, possibly, usually, necessarily. They apply to the propositions and to the inferential process.

(vi) rebuttals, that is, alternative claims which can also be inferred from the grounds, warrants, and the backing because of the modal quantification of propositions and inferential rules. Rebuttals can be overcome by either showing that they imply a smaller set of consistent propositions than the claim or by comparing the overall modal qualification of the rebuttals with the evaluation of the claims.
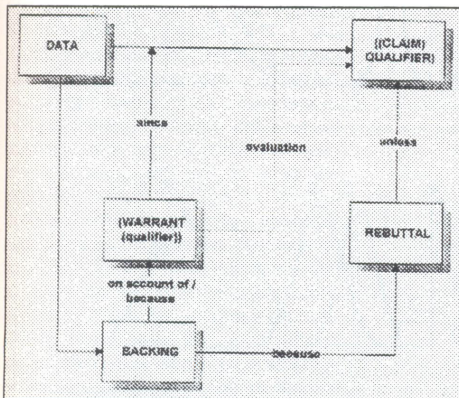

Figure 1: A modified version of Toulmin's (1964) model for syllogisms in argumentation. Toulmin's original model is indicated by upper case letters and bold lines.

These components are combined as shown in Figure 1 (Toulmin 1964, p. 104; the figure is slightly changed in order to avoid inconsistencies).

An example for this kind of syllogistic reasoning by means of analyzing chains of arguments is the determination of the probable price for a used book (see Figure 2).

Especially Figure 2 reveals the importance of quantifiers, implicit (...) or explicit (usually, always etc.), for the evaluation (qualification) of the claim. In order to develop a formalized version of Toulmin's approach to plausible reasoning, it is necessary to develop a common framework for the interpretation of explicit and implicit quantifiers and furthermore an algorithm for their concatenation. Zadeh (1983) has suggested to interpret quantifiers as fuzzy numbers in the [0,1] interval and to use the operations for fuzzy numbers (Dubois & Prade 1980) as the algorithm for their concatenation.
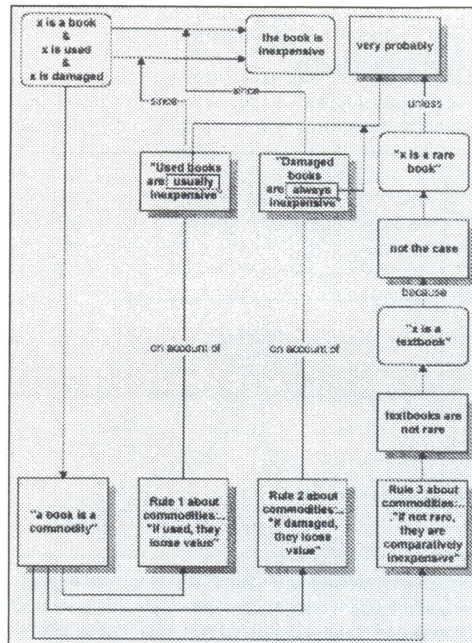

Figure 2: The application of the modified Toulmin model.

3. Fuzzy Numbers and Qualifiers

The meaning of quantities like "about 50 %" or "slightly below 0.3" (Smithson 1987) and the addition of "about 50 %" and "a bit more than 10 %" with the result "probably somewhat more than 60 %" seem to make sense immediately. However, it is not clear how this intuitive meaning is reflected in the formal definitions of fuzzy numbers and their rules of concatenation (Dubois & Prade 1980). The formal definitions allow for the proving of abstract theorems in fuzzy number theory and for checks of consistency but they do not provide any guidelines for the mapping of imprecise observable quantities into the different types of fuzzy numbers (_, s, z, s/z, or z\s numbers) and for the setting of parameters. On the other hand, Smithson's (1987) and others purely empirical approach characterizing a fuzzy number by a listing of relative frequencies is not sufficient either because he does not propose empirically testable rules for the concatenation of these numbers. Such rules however can be derived from results on approximate calculation in the areas of foreign exchange (Zimmer, 1984 b). For merely illustrative purposes, let us start with fuzzy numbers of the form "standard number + qualification" (e.g. "approximately .7"). Figure 3 represents this fuzzy number where the 'core', that is, .7, and the fuzzy upper and

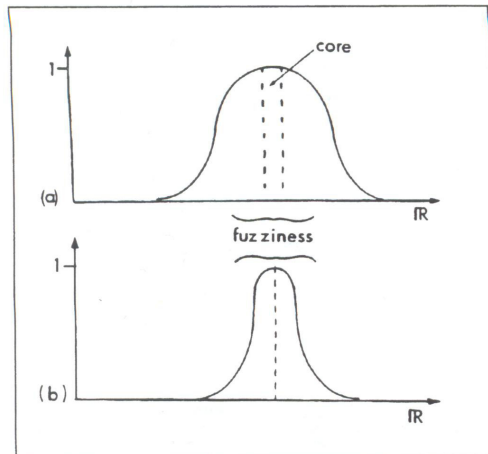# Decision Support for Marketing via Fuzzy Reasoning

Figure 3: Fuzzy numbers consisting of a core (or prototypical) meaning of 0.7 and fuzzy upper and lower boundaries. (a) is a fuzzy number with core intterval, (b) is a fuzzy number with a point-wise core.

lower boundaries, that is, the fuzziness due to the qualification, can be discriminated. The fuzzy number can now be represented by the following triple: lower boundary relative to the core, core, upper boundary relative to the core (.1/0.7, 0.7, .15/0.7).

Any two fuzzy numbers can be concatenated following these steps: (i) calculating the resulting core by means of standard arithmetics, by (ii) averaging the respective upper and lower boundaries, and by (iii) determining the resulting boundaries from the averaged boundaries in relation to the resulting core.

The operations with fuzzy numbers corresponding to the standard operations in arithmetics are illustrated in Figure 4a-d.

The described approach of handling the core and the fuzziness separately has been backed empirically, that is, the think-aloud protocols of the subjects reflect this procedure. For fuzzy numbers like 'several', 'most', or 'likely' the same procedure can be applied provided the core has been determined empirically.

4. Fuzzy Arithmetics as a Model for Reasoning

Starting with the experimental studies by Zimmer (1982, 1984 a and b) empirical evidence has been amassed for Yager's (1980) and Zadeh's (1983 a,b, 1984) claim that
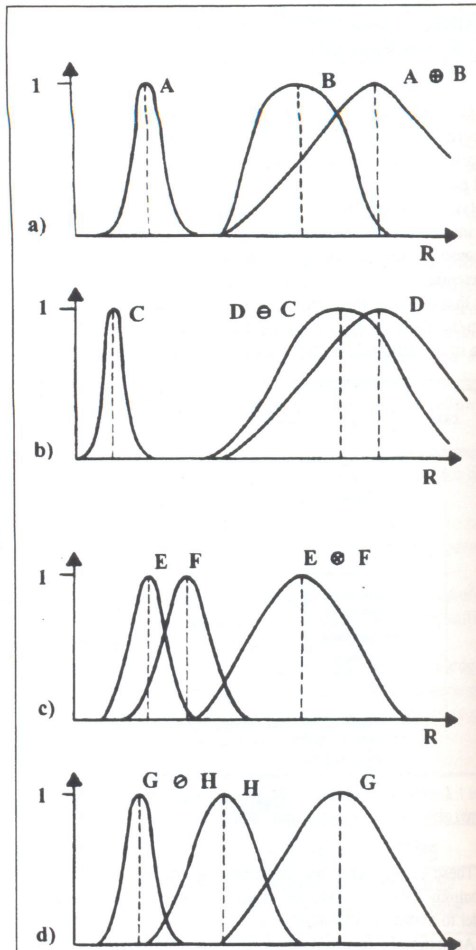

Figure 4

Operations with fuzzy numbers
a/ fuzzy addition ⊕
b/ fuzzy multiplication ○
c/ fuzzy substration ○
d/ Fuzzy division ⊘

fuzzy numbers can be used for the representation of generalized quantifiers (Barwise & Cooper 1981, Peterson 1979) and furthermore that human reasoning with these quantifiers can be modelled according to the operations with fuzzy numbers. As noted above, further experimental studies have led to modifications in the definition of fuzzy numbers as

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well as of operations with them. These modifications, however, are not crucial for the general claim.

From a formal point of view, quantifiers expressed as fuzzy numbers in the interval [0,1] and uncertainty expressions represented as fuzzy probabilities are comparable. Furthermore, in chains of argumentation (see Figure 2) both kinds of qualification can be found and should therefore be represented in a common framework for the use in intelligent systems e.g. expert systems (Zadeh 1983 c). Empirical analyses of uncertainty expressions (Zimmer 1983, 1986 a; Wallsten, Budescu, Rapoport, Zwick, Forsyth 1986; and Zwick & Wallsten, 1987) have consistently shown that verbal expressions like probable, likely, or toss-up can be expressed as fuzzy numbers. Different experimental techniques (e.g. pair comparison vs. staircase estimation), different forms of displays (e.g. circle segments vs. random dots), and different samples of uncertainty expressions (all expressions of a language community vs. only those expressions that a subject has in his/her personal active vocabulary) have led to seemingly conflicting results about the consistency of estimates and therefore the applicability of verbal uncertainty expressions in decision support or expert systems. There are two solutions for this problem: One consists in the Wallsten et al. approach (1986), that is, determining the fuzzy numbers for a complete lexicon of uncertainty expressions.

This leads to averaged meanings that can be assumed to be valid for an entire language community. By means of iterative methods (Zimmer 1986 b), ambiguous meanings (fuzzy numbers with more than one peak) can be resolved. The problem with this approach is that the individual's lexicon of uncertainty expressions might differ from that of the language community. The important advantage of this approach, however, is its generality. The other solution for the problem consists in concentrating on the individual's lexicon of uncertainty expressions.

Calibrating individual vocabularies of uncertainty expressions by means of staircase methods with random-dot displays Zimmer & Korndle (1987) has resulted in fuzzy numbers that can be represented by (i) single-peaked membership functions, (ii) of comparable shape and (iii) with the tendency towards a proportional relation between the value of the core and the fuzziness. To be more precise: In contrast to fuzzy numbers without interval bounds, the fuzziness in

the closed interval [0,1] is relative to the smaller distance of each core from the upper or lower limit. These qualitative aspects of the fuzzy numbers are consistent with the model described in part 2 above. It should be kept in mind that (iii) contradicts one of the theoretical assumptions of Zimmer (1982) and (1983), namely the assumption of equal informativeness on the entire scale of judgment, and therefore equal fuzziness for all uncertainty expressions in an individual active vocabulary. However, the consequence of the unequal informativeness (low in the central part and high in the extremes) is in accordance to the results report-

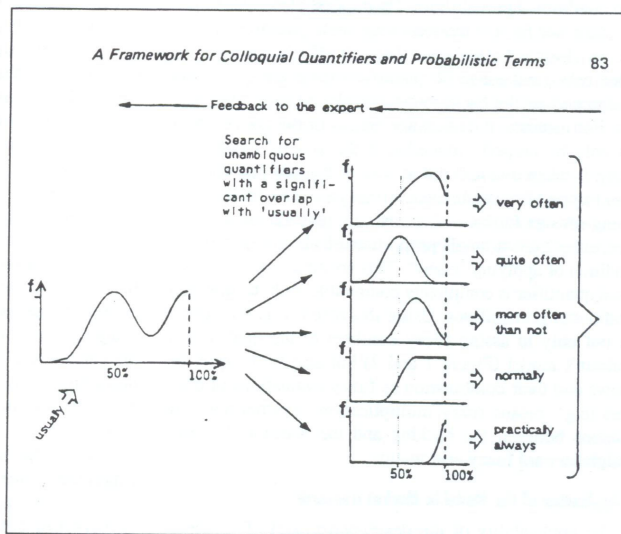A Framework for Colloquial Quantifiers and Probabilistic Terms   83

Figure 5: Interactive determination of unambiguous uncertainty expressions (Zimmer 1986b).

ed by Wallsten and his group (Wallsten et al. 1986).

The major disadvantage of this individualistic approach, namely its lack of generality, can be overcome by the procedure described in Zimmer (1986 b). It starts with the individual's expressions but maps them into the general lexicon. If a mapping does not result in a single-peaked fuzzy number or if the fuzziness is excessive, it is iteratively searched for the non-degenerate expression which captures best the initially intended meaning (see Figure 5).

During and by the interaction with this computer-controlled procedure, subjects learn to use only those expressions the meaning of which is in accordance with that of the language community. However, it restricts the expressive power of the individual lexicon.

The common framework for quantifiers and uncertainty expressions as established by the assignation of fuzzy numbers in [0,1] has to be complemented by a comparison of the algorithms of inference. The standard algorithms, that is,

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syllogistic resolution and Bayesian weighing of evidence are seemingly incomparable but since Zadeh (1983a) has shown that any form of syllogistic resolution can be modelled by fuzzy quantifiers and fuzzy operators (addition, multiplication, and conjunction) it is possible to use the same operators for Bayesian inference. There is only one additional operator necessary, namely division, for working with conditional probabilities. On the first glance, this operator does not fit into the reasoning with quantifiers. However, as Hormann (1983) and Zimmer (1986a) have shown, in the colloquial usage of quantifiers these are quite often conditioned on the background knowledge about the situation. For instance, the utterance "many of the convertibles" can only be properly modelled if the general meaning of 'many' is taken into account as well as the fact that convertibles form a very small subset of all cars. The implicit reasoning runs as follows: if the cars in question are convertibles, then even a small proportion of all cars fulfills the condition of applying "many". This construction of a conditional quantifier is completely compatible with the notion of conditional probabilities. Using this result, it is now possible not only to assign fuzzy numbers to the qualifiers in Toulmin's model (Figure 1 and 2) but also to interpret the arrows and their combination as fuzzy evaluations of operators (e.g. means fuzzy multiplication). Furthermore, the relations between the backing and the warrants becomes straightforward fuzzy arithmetics.

5. Application of the Model in Market Research

The applicability of the developed model of reasoning with fuzzy qualification has been tested in the field of market research. A leading German producer of snacks and cereals monitors the distribution and the sale of its products

by means of data provided by three different panels.

The trade panel estimates parameters for the turn-over in supermarkets and other outlets.

The household panel describes the buying behavior of a typical German family by asking 500 families to keep diaries of their buying acts.

Finally, the insertion panel monitors advertisements and determines how often a product is advertised and what price is asked for it.

Using these data for controlling the production and the marketing activities is difficult simply because of the amount of data. In cooperation with marketing specialists we have developed a simple constraint net for the parameters in question (see Fig. 6). This constraint net has been integrated into the reasoning model using it as the BACKING of the CLAIM. By inputting the actual estimates from the panels as DATA it has been possible not only to link the effects of marketing campaigns (e.g. rebates or advertising-cost allowance) to the general turn-over and to the final gains but also to take into account link internal data concerning production, purchase of raw material, price of re-providing etc.. In the original study these results have only been used as an advisatory system for the market researcher. In a follow-up study we have applied this model to the question of optimal price-setting for a German coffee-maker. By using our model it was possible to increase the prediction of the general turn-over to r = .75 as compared to the prediction using linear regression with a correlation coefficient of r = .25, that is, increasing the explained variance by a factor of 9.

A further possible application of this kind of combining expert knowledge (WARRANT and BACKING) and DATA consists in doing what-if analyses; by simulating the effects of marketing activities these can be fine-tuned to the overall goals of the corporation or the expected economic side conditions, for instance, by choosing a minimax strategy.
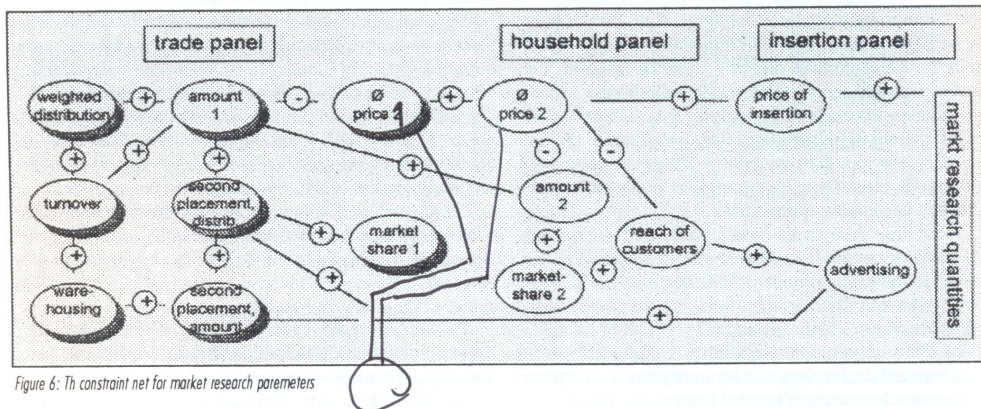
6. Conclusion

Figure 6: Th constraint net for market research paremeters

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The developed common framework for the two major kinds of information processing, namely decision making and reasoning, allows for modelling intricate nets of arguments by means of fuzzy arithmetics. It seems especially applicable to the development of decision support systems for marketing because in that setting the combination of decision making and reasoning is required.

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